Navigating the Green Fuel Transition

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Executive Summary

The shipping industry is entering a period of fundamental transformation, with future fuel selection offering a wide range of choices. Rather than converging on one successor to fuel oil, there are many options - LNG, methanol, ammonia, biofuels and future e-fuels. For shipowners ordering vessels that will operate into the 2050's, it's not just a question of cost, but which option will best meet the requirements of future carbon regulations, supply constraints and operational demands.

Each option has its own benefits and drawbacks. **LNG** is commercially mature (LNG dual-fuel vessels account for nearly 90% of the alternative-fueled vessel order book), is energy-dense and backed by established infrastructure and trained crews. However, LNG is still fossil-based and does not fix long-term carbon reduction goals, offering only a minor greenhouse gas benefit over heavy fuel oil. Methane-slip is also a major concern. **Methanol** is attractive mainly for its operational simplicity and will appeal to liner operators with predictable routes, but most supply is still fossil-based and green variants remain scarce. **Ethanol**, while energy-dense and already produced at scale (US, Brazil), lags behind methanol in industrial and marine supply chain integration. **Ammonia** promises near-zero carbon combustion and long-term viability but faces severe barriers in energy density, infrastructure and toxicity related safety risks. **Biofuels** may be useful as a compliance bridge but are not scalable as a primary fuel.

Fuel viability increasingly depends on trade route, vessel type, and regulatory exposure rather than a universal solution e.g., liner shipping can adopt methanol or ammonia more readily than flexible tramp operations reliant on LNG. Additional considerations may include methanol on Europe trading liner services, LNG on inter-Asia or tramp, and ammonia on selected long haul green corridors.

Ultimately, success will not be measured by picking the "perfect" fuel, but rather on supply-chain synchronisation. This is fundamentally a systems transition that incorporates elements of supply chain, ports, financing systems, regulations and human capability, rather than a purely technological one.

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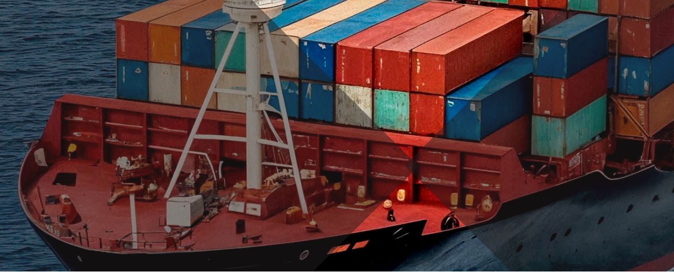

Article 1*

A. Introduction: The uncomfortable truth about maritime decarbonisation

Shipping is entering a fuel transition unlike any in its history. The industry is not converging on one obvious successor to fuel oil. Instead, it is fragmenting across several competing pathways, including LNG, methanol, ammonia, biofuels, and eventually, synthetic e-fuels, each with distinct technical requirements, economic implications, infrastructure needs, and safety risks.

This article explores the current landscape of alternative marine fuels, examining where each option stands in its development journey. More importantly, it offers a framework of key questions we believe shipowners should consider as they navigate this complex decision and determine which single or combination of fuel pathways best aligns with their fleet strategy and long-term ambitions.

For shipowners ordering assets with 20- to 30-year lives, the central question is no longer simply which fuel is cheapest today, but which fuel pathway is most resilient under future carbon, supply-chain and operational constraints. That challenge is intensified by the fact that regulatory frameworks, fuel economics and supply chains are still evolving, while vessels ordered today may remain in service well into the 2050s. The result is a growing strategic dilemma. LNG is commercially mature and available, but structurally exposed to future carbon pricing. Methanol is operationally attractive and rapidly scaling, but constrained by fuel availability and lifecycle emissions concerns. Ammonia promises near-zero carbon operations and long-term alignment with decarbonisation goals, but faces significant hurdles in safety, infrastructure, crew readiness, and cost.

The industry is therefore no longer asking a simple question about which fuel is cheapest. The more important question is becoming: which fuel pathway minimises long-term system risk?

That distinction matters because maritime decarbonisation is not merely an engineering challenge. It is simultaneously a logistics challenge, a financing challenge, a workforce challenge, and increasingly a geopolitical challenge.

The debate around alternative fuels often becomes overly simplified. LNG is frequently portrayed as a transitional fossil fuel with limited long-term relevance. Methanol is often described as the practical compromise. Ammonia is increasingly presented as the inevitable end-state fuel for deep-sea shipping. Yet reality is more nuanced. The competitiveness of each fuel depends heavily on trade routes, vessel types, regulatory exposure, operational flexibility, and access to infrastructure.

There will not be a universal fuel solution for shipping.

Instead, the industry is moving toward a portfolio world in which multiple fuels coexist across different segments and corridors. Liner operators on fixed Asia–Europe loops may adopt methanol or ammonia earlier because they can coordinate bunkering along dedicated green corridors. Tramp operators, which depend on operational flexibility and irregular routing, may remain dependent on LNG and conventional fuels much longer because no globally available alternative yet exists.

At the same time, shipping is not competing for fuels in isolation. Aviation, heavy industry, chemicals, and power generation are all competing for the same low-carbon molecules. Green methanol, bio-methanol, BioLNG, and low-carbon ammonia are likely to remain scarce and expensive through the 2030s because supply growth is struggling to keep pace with anticipated demand.

> ***The consequence is that fuel competition is increasingly becoming a competition for access.***

This article argues that the future fuel landscape will not be determined by a single technological winner. Instead, the fuels that scale fastest over the next two decades will be those capable of

* This article is part one of a three-part article series on Navigating the Green Fuel Transition

synchronising production, logistics, bunkering infrastructure, regulation, financing, and workforce capability simultaneously.

Viewed through that lens, LNG, methanol, and ammonia each reveal very different strengths and weaknesses.

B. Alternative fuels landscape – options, readiness and trade-offs

LNG: commercially mature but strategically vulnerable

LNG remains the most mature alternative-fuel ecosystem in shipping today. It benefits from large-scale upstream supply, established bunkering procedures, existing operational experience and deep familiarity across financiers, class societies and ports. But it is no longer the only fuel pathway moving beyond pilot stage: methanol, in particular, has now entered early commercial deployment.

LNG benefits from large-scale global production, a developed carrier fleet, established bunkering procedures, and extensive operational experience derived from decades of LNG carrier operations. More than any other fuel pathway, LNG offers shipowners immediate operational certainty.

This explains why LNG has continued to dominate alternative fuel vessel orders despite growing criticism from environmental groups.

From a technical perspective, LNG possesses the highest volumetric energy density among the major alternative fuels (excluding biodiesel) currently available to shipping. While still lower than conventional fuel oil, LNG requires significantly less storage volume than methanol or ammonia. This translates directly into better range performance and lower cargo penalties.

For long-haul routes, particularly deep-sea bulk and tramp operations, this advantage is substantial.

However, LNG's advantages come with significant complexity. LNG must be stored at approximately minus 162 degrees Celsius in cryogenic tanks. These systems are expensive, technically demanding, and space intensive. LNG vessels also require sophisticated boil-off gas management systems, insulation technologies, and strict safety procedures.

The capital expenditure implications are considerable. LNG-fuelled vessels typically carry a twelve to eighteen percent newbuild premium compared with conventional vessels, while retrofits can cost tens of millions of dollars.

Despite these costs, LNG currently offers the strongest total cost of ownership profile among the major alternative fuels.

That is because shipping's economics are still driven largely by fuel availability and operational maturity rather than absolute decarbonisation performance.

LNG infrastructure already exists across major trade routes. Singapore, Rotterdam, Northern Europe, the United States Gulf Coast, China, and the Middle East all possess expanding LNG bunkering capabilities. LNG also benefits from established financing familiarity. Banks, insurers, classification societies, and ports already understand the fuel.

For LNG, crew competence frameworks and shipboard practice are materially more mature than for other emerging fuels. Training standards are mature under the IMO's International Code of Safety for Ships using Gases or other Low-flashpoint Fuels, and a large base of trained seafarers already exists.

This operational maturity matters more than many realise.

One of the least discussed constraints in maritime decarbonisation is human capital. Hundreds of thousands of seafarers will require retraining over the next decade to operate alternative fuel systems safely. LNG is currently the only pathway where crew readiness exists at meaningful scale.

Yet LNG's structural vulnerability is increasingly clear.

Although LNG reduces carbon dioxide emissions compared with conventional fuel oil, it remains a fossil fuel pathway. More critically, LNG suffers from methane slip—the release of unburned methane during combustion and fuel handling.

Methane is a far more potent greenhouse gas than carbon dioxide over shorter time horizons. As regulators shift toward lifecycle emissions accounting rather than tailpipe-only emissions, methane slip is becoming a major strategic liability.

This matters increasingly under FuelEU Maritime, which is already in force, and under the EU ETS, whose shipping scope further expands in 2026. Furthermore, potentially under the IMO's proposed Net Zero Framework, decisions are being shaped to address its implications on future investment decisions. As a result, fuel economics can no longer be assessed on commodity price alone.

> ***Increasingly, the relevant equation is becoming: Fuel cost plus carbon liability plus compliance penalties.***

Under this framework, LNG's competitiveness deteriorates over time.

In the short term, LNG remains commercially attractive because its commodity cost advantage still outweighs regulatory penalties. But in the medium and long term, carbon pricing mechanisms begin to erode this advantage.

Over time, LNG's economics are likely to become more route and regulation sensitive. Its long-term competitiveness will depend increasingly on methane-slip treatment, carbon pricing, and the availability of lower-GHG drop-in substitutes such as BioLNG or replaced entirely by synthetic e-LNG. This creates a paradox.

LNG is likely the most commercially rational fuel today, particularly for tramp and long-haul shipping. Yet it is also among the most strategically exposed to future carbon regulation.

For many shipowners, LNG therefore represents not a permanent solution, but a hedge against transition uncertainty.

Methanol: the pragmatic compromise

If LNG represents operational maturity, methanol represents operational pragmatism. Methanol's greatest strength is not its carbon profile. It is its simplicity.

Compared with cryogenic fuels, methanol benefits from liquid-fuel handling characteristics that allow parts of existing liquid fuel storage infrastructure and transfer ecosystem to be adapted rather than rebuilt from scratch. But "adapted" is the key word: dedicated standards, crew competencies, materials selection, detection systems and bunkering procedures are still required. This operational familiarity has made methanol especially attractive to liner operators.

Major container lines are increasingly adopting methanol-ready vessels because liner shipping possesses the one characteristic methanol requires most: predictability.

Fixed trade routes and scheduled port calls allow operators to coordinate fuel supply agreements and dedicated bunkering strategies. Green corridors can therefore emerge around concentrated demand.

This is much harder in tramp shipping, where vessels operate irregular routes and cannot rely on consistent fuel availability. Technically, methanol's main weakness is energy density.

Methanol possesses roughly 40% volumetric energy density of conventional fuel oil. Vessels therefore require significantly larger fuel tanks, reducing cargo capacity or increasing design complexity. This limitation becomes especially important on ultra-long-haul routes where range and fuel flexibility are critical. However, methanol compensates for this disadvantage with storage simplicity.

Unlike LNG's cryogenic cylindrical tanks, methanol tanks can often be integrated more flexibly into vessel designs. Retrofitting costs are therefore lower, and the broader infrastructure transition is less disruptive. This interoperability advantage is strategically important.

Shipping's fuel transition is constrained not only by fuel availability, but also by infrastructure compatibility. LNG, methanol, and ammonia are largely incompatible ecosystems.

Choosing one pathway creates long-term technological lock-in.

Methanol's ability to leverage existing chemical handling systems gives it a powerful transitional advantage. From an environmental perspective, however, methanol is far more complicated than often portrayed. Methanol is not inherently green.

Most methanol produced today remains fossil-derived, typically from natural gas or coal. Its lifecycle emissions therefore vary dramatically depending on feedstock and production pathway.

Blue methanol, produced from fossil feedstock with carbon capture, may also play a useful transition role, provided its lifecycle emissions reductions are credibly certified and recognised under applicable regulatory frameworks. Green methanol, produced from renewable electricity and captured carbon dioxide, offers substantially lower lifecycle emissions. Bio-methanol, derived from sustainable biomass or waste streams, also provides significant reductions.

Yet these fuels remain scarce.

The problem is not technological feasibility. The problem is molecule availability. Shipping is competing directly with aviation, chemicals, and industrial sectors for green methanol supply.

Aviation in particular may outcompete shipping for sustainable methanol-derived fuels because it possesses fewer decarbonisation alternatives and faces increasingly stringent sustainable aviation fuel mandates. This competition is likely to keep green methanol supply tight and premiums elevated are likely to persist well into the 2030s.

Still, methanol occupies a strategically attractive middle ground. Compared with LNG, methanol offers better long-term alignment with decarbonisation policy. Compared with ammonia, methanol offers substantially lower operational and safety complexity.

This explains why methanol is increasingly viewed as the shipping industry's most practical transition fuel. It is neither the cheapest nor the cleanest option. But it may be the most deployable at scale within the next decade. Safety considerations further reinforce this position.

Methanol is flammable and burns with an almost invisible flame, creating unique firefighting challenges. However, its hazards are relatively familiar within existing chemical handling industries. The maritime sector can therefore adapt existing safety practices rather than invent entirely new systems. This matters because safety governance is becoming a decisive determinant of fuel adoption.

Fuels with mature safety ecosystems scale faster.

LNG already possesses globally harmonised operational procedures. Methanol can adapt established chemical handling frameworks. Ammonia, by contrast, requires the industry to develop an entirely new maritime safety paradigm.

Ethanol: the overlooked cousin in the alcohol fuel debate

While methanol has emerged as the dominant alcohol-based marine fuel attracting commercial attention, ethanol is quickly emerging as viable candidate after years of being under-discussed. Especially with engine makers announcing ethanol compatible engines it now places ethanol as a potentially important parallel pathway in shipping's energy transition.

The comparison between methanol and ethanol is increasingly relevant because both fuels belong to the alcohol family, share certain handling characteristics, and can in some cases leverage overlapping infrastructure ecosystems. Yet the maritime industry has largely converged around methanol rather than ethanol for strategic and technical reasons.

At first glance, ethanol appears attractive.

It possesses a higher volumetric energy density than methanol, reducing some of the storage penalties associated with alcohol fuels. Ethanol is also already produced globally at substantial scale, particularly in Brazil and the United States, where mature agricultural supply chains support large bioethanol industries.

In addition, ethanol benefits from extensive experience in land-based transportation fuels through blending programmes in gasoline markets. However, shipping's requirements differ fundamentally from those of road transport.

The maritime sector prioritises fuel availability at major bunker hubs, compatibility with marine engine systems, scalability for deep-sea operations, lifecycle carbon intensity, and long-term synthetic fuel potential. It is across these dimensions that methanol has generally gained stronger momentum.

One reason is industrial integration.

Methanol already occupies a major role within global chemical and petrochemical industries. Existing storage terminals, handling systems, and maritime transportation networks for methanol are therefore relatively mature.

By contrast, ethanol infrastructure remains more concentrated around agricultural and regional fuel markets. This distinction matters because shipping's transition depends heavily on global bunker availability rather than isolated production capacity.

Another critical difference lies in future decarbonisation pathways.

Green methanol can be produced synthetically using captured carbon dioxide and green hydrogen, making it highly compatible with emerging power-to-liquid fuel systems. Bio-methanol can also be derived from municipal waste, biomass residues, and biogenic carbon streams.

Ethanol production, by contrast, remains more heavily associated with agricultural feedstocks such as corn and sugarcane. This creates both opportunities and vulnerabilities.

Brazilian sugarcane ethanol possesses one of the strongest lifecycle emissions profiles among biofuels and could potentially support maritime decarbonisation in specific regional corridors. However, crop-based ethanol also raises persistent concerns around land use, water intensity, food-versus-fuel debates, and long-term feedstock scalability.

These concerns become especially important if shipping seeks truly global deployment. Methanol's broader feedstock flexibility therefore provides a major strategic advantage. Technically, ethanol also presents some marine operational challenges.

Like methanol, ethanol is hygroscopic, meaning it absorbs water easily. This creates storage and fuel quality management issues in marine environments. Ethanol can also contribute to material compatibility concerns and corrosion in certain systems if infrastructure is not specifically adapted. However, these challenges are generally manageable and not fundamentally prohibitive.

In fact, several engine manufacturers are exploring dual-fuel and flexible alcohol-fuel engine designs capable of operating on methanol, ethanol, or combinations of both. This raises an interesting long-term possibility.

The future alcohol-fuel ecosystem in shipping may not ultimately become a strict methanol-versus-ethanol competition. Instead, certain regions may evolve blended or parallel alcohol-fuel pathways depending on local feedstock availability and industrial strengths.

Latin America, for example, may emerge as a more significant ethanol-linked maritime fuel producer given its established bioethanol ecosystem. Northern Europe and East Asia, meanwhile, may continue prioritising methanol because of stronger synthetic fuel ambitions and industrial chemical integration.

Still, methanol retains several decisive advantages.

Marine engine development for methanol is significantly more advanced. Bunkering investments are already accelerating around methanol-specific infrastructure. Large container operators have committed publicly to methanol pathways, creating early demand concentration that reinforces network effects. This commercial momentum matters enormously.

Shipping transitions historically accelerate not simply because of technical superiority, but because industrial ecosystems begin coordinating around a dominant pathway.

Ethanol therefore risks becoming strategically overshadowed by methanol even if some technical and environmental characteristics remain attractive. There is also an important economic consideration.

The maritime industry is unlikely to support entirely separate global infrastructure ecosystems for multiple alcohol fuels unless strong regional advantages justify doing so. Ports, bunker suppliers, and shipowners are already under immense capital pressure from LNG, methanol, ammonia, and biofuel investments.

As a result, the market may naturally consolidate around the alcohol fuel with the strongest industrial alignment and largest early mover ecosystem. At present, that fuel is methanol. Nevertheless, ethanol should not be dismissed.

It may still play meaningful niche or regional roles, particularly where bioethanol production is abundant and competitive. Ethanol may also emerge as an intermediate blending component or feedstock contributor within broader synthetic fuel systems.

More importantly, the comparison between ethanol and methanol reveals a larger truth about shipping's fuel transition.

> ***Fuel adoption is not determined solely by chemistry. It is determined by ecosystem coordination.***

The fuels that ultimately scale are those capable of aligning feedstocks, industrial production, infrastructure, financing, engine development, regulation, and commercial confidence simultaneously. In that contest, methanol currently possesses a significant first-mover advantage over ethanol.

Ammonia: the long-term contender with the largest barriers

Among all alternative marine fuels, ammonia provokes the strongest reactions. To its advocates, ammonia represents shipping's most credible pathway to full decarbonisation. To its critics, it introduces unacceptable operational and safety risks. Both perspectives contain truth.

Ammonia's attraction is that it contains no carbon and can avoid CO_2 emissions at the point of use. However, under the well-to-wake accounting framework, green ammonia whilst having a lower embedded GHG emission liability compared to blue or grey ammonia, the issues from NOx and nitrous oxide emissions post combustion will still need to be managed to ensure decarbonisation benefits be it commercial or environmental.

The long-term economics of shipping fuels are likely to converge toward a world where carbon costs dominate commodity costs. In such a scenario, ammonia's current fuel price disadvantage narrows substantially. This is why many analysts increasingly view ammonia as a leading candidate for deep-sea decarbonisation beyond 2040. Yet ammonia's barriers remain enormous.

The first is energy density. Ammonia possesses among the lowest volumetric energy densities of the major marine fuel candidates. Vessels require approximately two-and-a-half to three times the storage volume compared with conventional fuel oil. This creates significant cargo penalties and design challenges, especially for long-haul operations.

The second barrier is infrastructure. Unlike LNG or methanol, ammonia lacks a mature maritime supply chain. Although ammonia is already traded globally within the fertilizer industry, the marine fuel ecosystem barely exists. Bunkering infrastructure remains limited, with activity still concentrated in pilot projects at a handful of ports.

Ports face especially difficult challenges.

Ammonia requires refrigerated or pressurised storage systems, corrosion-resistant materials, and extensive safety exclusion zones. Toxic plume modelling and emergency response capabilities must also be incorporated into port design. For densely populated ports such as Singapore, land constraints and public acceptance become major considerations.

The third and perhaps most important barrier is safety. Ammonia fundamentally changes the nature of maritime fuel risk. LNG and methanol primarily present flammability and explosion hazards.

Ammonia's dominant risk is toxicity. Exposure can cause severe respiratory injury and poses acute dangers to crews, port workers, and nearby populations. As a result, ammonia operations require entirely different safety philosophies.

Ammonia therefore presents the highest crew risk compared to other alternative fuels, with significant concerns over crew competency to safely manage ammonia's acute toxicity, corrosive properties, stringent personal protective equipment discipline, gas detection protocols, and emergency evacuation procedures. This means that ammonia-fuelled operations will require a much higher level of safety engineering and operational discipline, including advanced gas detection systems, water curtain dispersal technologies, segregated fuel systems, specialised protective equipment, and intensive emergency response protocols all become necessary.

This has profound implications for workforce readiness. Shipping is accustomed to handling flammable fuels but handling toxic fuels at large scale is a different challenge altogether. The question is no longer only whether ammonia engines, storage tanks and bunkering systems can be engineered. It is whether the broader operating ecosystem – seafarers, ship managers, ports, bunker suppliers, emergency responders, regulator, and insurers can build the competence and confidence needed to support operations.

Ammonia's barriers remain formidable, but important foundations have already been established. Interim IMO safety guidance exists, pilot bunkering has taken place at leading ports, and engine developers are moving towards commercial deployment. However, the industry still faces significant readiness gap. These include a shortage of seafarers trained for ammonia operations, limited preparedness among port authorities, emergency responders and insurers and evolving regulatory frameworks under the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers. The remaining challenge is to convert that progress into routine, scalable, insurable operations.

This means ammonia's bottleneck may ultimately be human capability rather than engineering capability.

There is another critical issue often overlooked in discussions around ammonia: interoperability. Ammonia represents the least interoperable of the major fuel pathways.

LNG infrastructure cannot easily transition to ammonia. Methanol systems are largely incompatible. Engines, storage systems, pipelines, pumps, bunker vessels, and safety procedures all require dedicated configurations. This makes ammonia a fundamentally greenfield ecosystem.

Where LNG extends existing gas infrastructure and methanol leverages liquid fuel systems, ammonia requires large portions of the maritime value chain to be rebuilt. That distinction has major capital implications.

Shipowners considering ammonia are not simply selecting a fuel. They are effectively committing to an entirely separate industrial system.

Still, ammonia's long-term strategic logic remains compelling. Unlike biofuels, ammonia is not constrained by finite biomass feedstocks. Unlike LNG, it avoids carbon lock-in. Unlike methanol, it may ultimately achieve stronger cost competitiveness under deep decarbonisation regimes.

Ammonia's challenge is timing.

Ammonia may become highly competitive after 2040, but shipping must survive the 2025–2040 transition period first.

Biofuels: the hidden bridge in maritime decarbonisation

One of the most important realities of shipping's fuel transition is that the industry is unlikely to move directly from fossil fuels to fully green fuels. Instead, maritime decarbonisation will almost certainly pass through an extended biofuel phase.

Biobased fuels, i.e., biodiesel variants from used cooking oils, i.e., FAME and hydrotreated vegetable oils (HVO) or also known as renewable diesel is already being used as a compliant fuel to support shipping decarbonisation targets. Adoption remains limited due to current price premiums. However, biofuels provide shipowners with a practical compliance lever. Its flexibility as a drop in with varying blended percentages with MDO, HFO or VLSFO i.e., 20% (B20), 24% (B24), and in some cases 100% replacement of the heavy fuel oil i.e., B100, provides options for cost optimisation with respect to compliance management. Biofuels can help shipowners manage exposure to emissions-related regulations and costs, including carbon pricing, vessel efficiency requirements, and green-fuel mandates, without requiring immediate wholesale changes to vessel design or bunkering infrastructure.

This has also opened up commercial opportunities for freight forwarders and shipping companies to offer cargo owners options to reduce their Scope 3 emissions for brand enhancement, green consumer acceptance and green procurement policy compliance. However, stricter biofuel supply chain assurance, including lifecycle-emissions accounting, to ensure robust traceability and integrity of green environmental attributes will be needed to curtail fraud and green washing. Especially since their importance lies not in their scalability, but in their ability to reduce lifecycle emissions using existing or semi-existing infrastructure.

Therefore, biodiesel, BioLNG, bio-methanol and bio-ethanol are increasingly being considered as critical bridging solutions optimising the cost of compliance, as their availability and accessibility ramps up.

Other than biodiesel, BioLNG is especially attractive because it is chemically identical to conventional LNG. Existing LNG vessels, storage systems, pipelines, and bunkering infrastructure can therefore use BioLNG without modification. This interoperability advantage significantly reduces transition friction.

However, BioLNG faces severe feedstock limitations. Sustainable biomethane production depends on waste streams, agricultural residues, and other limited biomass sources. Competing sectors such as road transport, heating, and power generation are already contesting these resources. As a result, BioLNG is unlikely to scale sufficiently to supply the majority of maritime energy demand. Instead, it will probably function as a strategic blending fuel.

Shipowners may use BioLNG selectively to reduce compliance penalties under FuelEU Maritime or future IMO carbon pricing systems. Bio-methanol occupies a similar position.

Like green methanol, bio-methanol offers significant lifecycle emissions reductions and integrates relatively easily into existing methanol pathways. Yet it too faces intense competition from aviation and chemicals.

> ***The key insight is that biofuels are becoming less important as primary energy sources and more important as compliance instruments.***

Their value increasingly derives from their ability to reduce regulatory exposure. This transforms shipping economics. Fuel selection is no longer based solely on commodity pricing. It increasingly revolves around carbon optimisation strategies. A vessel consuming expensive bio-methanol may still achieve lower total operating costs if compliance credits and avoided penalties outweigh the fuel premium. This is particularly important on Europe-facing routes where FuelEU Maritime and the EU Emissions Trading System create strong incentives for lower lifecycle emissions.

C. Key Considerations for Shipowners before committing to a fuel pathway

The geography of fuel choice

One of the most misleading assumptions in shipping's fuel debate is the idea that fuel competitiveness is global.

> ***In reality, fuel choice is becoming increasingly corridor-specific.***

Different trade routes possess different regulatory exposures, bunkering ecosystems, operational constraints, and fuel economics. Asia–Europe trades are among the most regulation-intensive corridors in global shipping. FuelEU Maritime, EU ETS exposure, and future IMO carbon pricing all combine to create powerful incentives for lower-carbon fuels.

As a result, methanol and biofuel blends are likely to gain traction earliest on these routes. The emergence of dedicated green corridors between Singapore, the Middle East, and Northern Europe further reinforces this dynamic. Ammonia may also gain traction on these long-haul liner routes because fixed schedules allow dedicated bunkering investments.

By contrast, intra-Asia trades remain far more cost-sensitive and less regulation-driven. LNG therefore retains strong advantages across Asia–Asia operations because infrastructure already exists and carbon penalties remain relatively limited.

Asia–Africa routes present a different challenge altogether. Here, infrastructure scarcity rather than regulation becomes the dominant constraint. Alternative fuels remain difficult to deploy because bunkering ecosystems are fragmented and inconsistent. Under such conditions, fuels with lower energy density and limited availability become operationally problematic.

Meanwhile, Asia–Americas trades increasingly resemble hybrid corridors. Strong LNG production from the United States supports continued LNG competitiveness, while methanol availability from the Gulf Coast and Caribbean also expands.

These route differences create an important strategic implication. There will not be a single fuel transition. Instead, fleets themselves may diversify.

A global operator may deploy methanol vessels on Europe-facing liner services, LNG vessels on intra-Asia or tramp operations, and eventually ammonia vessels on selected long-haul green corridors.

This portfolio approach may ultimately prove more resilient than attempting to standardise around a single fuel.

Liner versus tramp shipping: the overlooked dividing line

The split between liner and tramp shipping may ultimately become one of the defining fault lines in maritime decarbonisation.

Liner operators possess structural advantages in fuel transition. Fixed schedules, predictable routes, concentrated port calls, and long-term cargo relationships allow liner companies to coordinate fuel procurement, infrastructure investments, and compliance strategies.

This makes methanol and eventually ammonia viable. Container shipping has therefore emerged as an early adopter of alternative fuels.

Tramp shipping faces a much harder problem. Bulk carriers and tankers operate flexible routes based on spot cargo demand. Their commercial success depends heavily on operational adaptability. Alternative fuels complicate this flexibility.

Methanol and ammonia require predictable bunkering ecosystems that tramp operations often cannot guarantee. Lower energy density also increases bunkering frequency, further constraining routing flexibility.

LNG currently appears to be the most scalable alternative fuel for meaningful tramp adoption, given its relative availability and infrastructure base. Even then, LNG's infrastructure coverage still lags far behind conventional fuel systems. This suggests a bifurcated decarbonisation pathway.

Liner shipping is likely to decarbonise earlier and faster because fuel infrastructure can be concentrated around major corridors.

Tramp shipping may transition much more slowly because it requires globally available and operationally flexible fuel systems. This distinction matters for policymakers.

A regulatory framework designed around liner shipping realities may inadvertently penalise tramp operators disproportionately

Supply chains, not engines, will decide the winners

The shipping industry often frames alternative fuels primarily as a technology race. In reality, the decisive factor may be supply chain synchronisation. A fuel only becomes commercially viable when production, transportation, storage, bunkering, regulation, financing, safety systems, and workforce capability all scale together.

LNG succeeded because its full ecosystem matured over decades. Methanol is advancing because it can leverage existing liquid fuel systems. Ammonia faces the hardest challenge because nearly every layer of the ecosystem must scale simultaneously.

Production is particularly critical. Green fuels depend heavily on renewable electricity and green hydrogen. Massive renewable energy expansion is therefore required simply to produce sufficient fuel volumes. This introduces geographic implications.

Regions with abundant renewable resources—Australia, the Middle East, Latin America, parts of Africa—may emerge as major exporters of green ammonia and synthetic fuels.

Shipping routes themselves may therefore evolve around future fuel production hubs.

At the same time, bunkering is becoming a universal bottleneck. Even LNG faces growing congestion pressures around bunker vessel availability, terminal access, and scheduling. Alternative fuel adoption is therefore increasingly constrained not by theoretical fuel production, but by last-mile delivery.

Ports face difficult investment decisions. Space is limited. Building parallel LNG, methanol, and ammonia ecosystems simultaneously is capital-intensive and operationally challenging. This may force ports to prioritise specific fuel pathways, reinforcing regional fragmentation.

Financing the transition

Capital allocation is becoming one of the defining challenges of maritime decarbonisation. Shipowners are being asked to make long-duration investments amid profound uncertainty. The financing community increasingly recognises that transition risk now extends beyond fuel price volatility. Stranded asset risk is becoming central.

A vessel optimised for LNG may face declining competitiveness under future carbon pricing. An ammonia vessel may struggle if fuel infrastructure scales too slowly. Methanol vessels may face fuel scarcity or persistent price premiums.

This uncertainty is reshaping lending behaviour. Banks and investors are increasingly evaluating vessels not merely on current earnings potential, but on future regulatory resilience. The Poseidon Principles and broader ESG-linked financing frameworks are supporting this shift.

Access to capital may therefore increasingly favour vessels aligned with lower lifecycle emissions trajectories. However, there is also growing recognition that transition pathways must remain commercially survivable.

> ***A theoretically perfect fuel pathway that destroys operating economics is unlikely to scale.***

This is why many shipowners continue ordering LNG vessels despite criticism. The fuel may not represent the ultimate end-state solution, but it provides operational and financial certainty during a highly uncertain transition period.

The strategic mistake of searching for a single winner

Perhaps the greatest strategic mistake the maritime industry could make is assuming that one fuel will dominate globally. The future fuel landscape will almost certainly remain pluralistic.

Different vessel classes, trade routes, regulatory exposures, and operational models will favour different fuels.

LNG may dominate transitional tramp shipping.

Methanol may emerge as the leading transition fuel for liner operations and regulated corridors.

Biofuels may function primarily as compliance optimisation tools.

Ammonia may eventually become the preferred fuel for deep-sea zero-carbon shipping after infrastructure and safety systems mature.

Synthetic e-fuels may later emerge where renewable energy abundance allows competitive production.

This fragmentation creates challenges, but it also provides resilience. Shipping has historically adapted successfully to fuel diversity. The industry already manages heavy fuel oil, marine gas oil, LNG, LPG, and numerous cargo-related chemical systems simultaneously. The future may simply involve a more complex version of this diversity.

D. Conclusion: from fuel transition to systems transition

The maritime decarbonisation debate often focuses excessively on fuels themselves. But shipping is not merely undergoing a fuel transition. It is undergoing a systems transition.

The winners in this race will not necessarily be the fuels with the lowest theoretical emissions. They will be the fuels capable of integrating successfully into real-world commercial shipping systems.

LNG succeeds today because its ecosystem already exists.

Methanol is gaining momentum because it balances operational simplicity with improving decarbonisation potential especially with its bio-methanol variant.

Bio-ethanol having complete interoperability with methanol engines, fuel delivery systems and bunkering infrastructure is emerging quickly as an alternative companion.

Ammonia remains strategically compelling because it aligns strongly with long-term carbon pricing and zero-carbon ambitions.

Yet none of these fuels solves the entire problem.

LNG remains exposed to carbon liabilities.

Biodiesel, methanol, bio-methanol and bio-ethanol faces molecule scarcity and lifecycle scrutiny.

Ammonia confronts immense infrastructure, safety, and workforce challenges.

The implication is that no single fuel is likely to dominate, and strategic adaptability will matter more.

Shipowners that succeed over the next two decades are unlikely to be those that predict the perfect fuel. They are more likely to be those that build flexible fleets, secure diversified fuel access, manage regulatory exposure intelligently, and invest early in operational capability. Furthermore, these shipowners will need upskill and/or reskill their workforce manning the vessels to operate the next generation of vessels.

Crew risk is therefore a major operational consideration. Ship management companies are ramping up their own training facilities and curriculum to prepare their seafarers and engineers to be operationally ready for the new fuels. This is to ensure not only their personal safety but operational reliability of the vessels safeguarding the asset, the cargo, and the environment. At the same time, government funded training facilities are also being established as IMO revises their global safety and competency treaty described in the Standards of Training, Certification, and Watchkeeping (STCW) for Seafarers.

Fuel optionality may define fleet strategy, but crew competence will determine whether that strategy can be executed safely and reliably.

The shipping industry has always evolved through long cycles of infrastructure and operational adaptation. This transition will be no different. But unlike previous eras, the defining challenge is not merely moving cargo efficiently. It is learning how to move cargo competitively in a carbon-constrained world. And in that world, the central question is no longer simply which fuel is best.

The real question is which fuel ecosystem can scale fast enough, safely enough, and economically enough to support global trade itself. That answer remains unwritten.

But one thing is already clear: the maritime energy transition will not be decided in engine rooms alone. It will be decided across supply chains, ports, financing systems, regulations, and human capability.

In other words, the future of shipping will depend not only on green attributes of the molecules, but on the systems that support them.

For fuel strategy, shipowners need to undertake a fleet-specific, sustainability-driven, and commercially realistic analysis based on the nature and circumstances of the use of the ship, vessel type, trade routes, cost of building/retrofitting, and forecast fuel availability, crew readiness, as well the expected vessel utilisation.

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